would be ſo turned, that the point A ſhall move toward B, and the point C toward D; but if it were in any other part of the circle, either between H and C, or between I and A, the line AC would be turned the contrary way. Hence it follows, ~~that as~~ this ſolid ring turns round the center of the earth, the parts of this ring between A and H, and between C and I, are ſo influenced by the ſun, that they will endeavour, ſo to change the ſituation of the line AC as to cauſe the point A to move toward B, and the point C to move toward D; but all the parts of the ring between H and C, and between I and A, will have the oppoſite tendency, and diſpoſe the line AC to move the contrary way. And ſince theſe laſt named parts are larger than the other, they will prevail over the other, ſo that by the action of the ſun upon this ring, the line AC will be ſo turned, that A ſhall continually be more and more moving toward D, and C toward B. Thus no ſooner ſhall the ſun in its viſible motion have departed from A, but the motion of the line AC ſhall haſten its meeting with C, and from thence the motion of this line ſhall again haſten the ſun's ſecond conjunction with A; for as this line ſo turns, that A is continually moving toward D, ſo the ſun's viſible motion is the ſame way as from S toward T.

49. THE moon will have on this ring the like effect as the ſun, and operate on it more ſtrongly, in the ſame proportion as its force on the ſea exceeded that of the ſun on the ſame. But the effect of the action of both luminaries will be greatly diminiſhed by reaſon of this ring's being connect-

ed to the reſt of the earth; for by this means the ſun and moon have not only this ring to move, but likewiſe the whole globe of the earth, upon whoſe ſpherical part they have no immediate influence. Beſide the effect is alſo rendred leſs, by reaſon that the prominent part of the earth is not collected all under the equator, but ſpreads gradually from thence toward both poles. Upon the whole, though the ſun alone carries the nodes of the moon through an intire revolution in about 19 years, the united force of both luminaries on the prominent parts of the earth will hardly carry round the equinox in a leſs ſpace of time than 26000 years.

50. To this motion of the equinox we muſt add another conſequence of this action of the ſun and moon upon the elevated parts of the earth, that this annular part of the earth about the equator, and conſequently the earth's axis, will twice a year and twice a month change its inclination to the plane of the earth's motion, and be again reſtored, juſt as the inclination of the moon's orbit by the action of the ſun is annually twice diminiſhed, and as often recovers its original magnitude. But this change is very inſenſible.

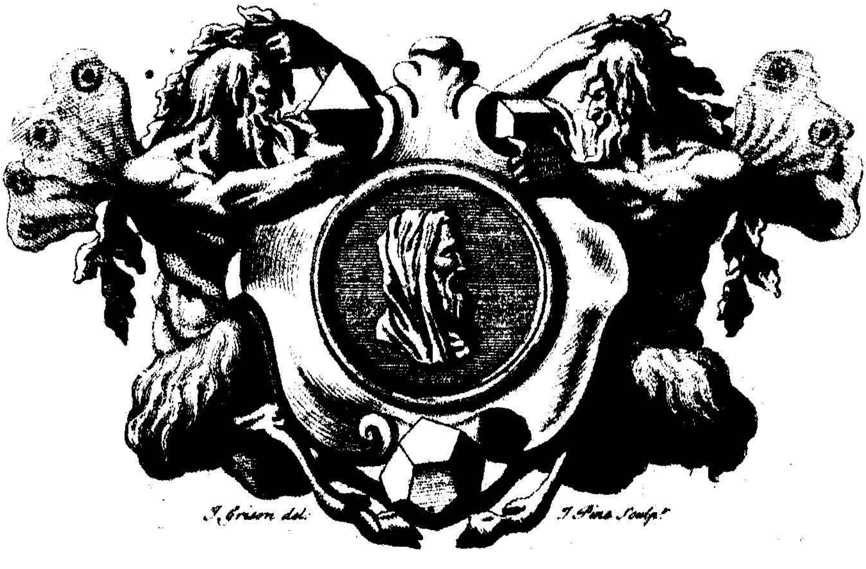
51. I ſhall now finiſh the preſent chapter with our great author's inquiry into the figure of the ſecondary planets, particularly of our moon, upon the figure of which its fluid parts will have an influence. The moon turns always the ſame ſide towards the earth, and conſequently revolves but once round its axis in the ſpace of an entire month;

for

for a ſpectator placed without the circle, in which the moon moves, would in that time obſerve all the parts of the moon ſucceſſively to paſs once before his view and no more, that is, that the whole globe of the moon has turned once round. Now the great ſlowneſs of this motion will render the centrifugal force of the parts of the waters very weak, ſo that the figure of the moon cannot, as in the earth, be much affected by this revolution upon its axis: but the figure of thoſe waters are made different from ſpherical by another cauſe, viz. the action of the earth upon them; by which they will be reduced to an oblong oval form, whoſe axis prolonged would paſs through the earth; for the ſame reaſon, as we have above obſerved, that the waters of the earth would take the like figure, if they had moved ſo ſlowly, as to keep pace with the moon. And the ſolid part of the moon muſt correſpond with this figure of the fluid part: but this elevation of the parts of the moon is nothing near ſo great as is the protuberance of the earth at the equator, for it will not exceed 93 engliſh feet.

52. The waters of the moon will have no tide, except what will ariſe from the motion of the moon round the earth. For the converſion of the moon about her axis is equable, whereby the inequality in the motion round the earth diſcovers to us at ſome times ſmall parts of the moon's ſurface towards the eaſt or weſt, which at other times lie hid; and as the axis, whereon the moon turns, is oblique to her motion round the earth, ſometimes ſmall parts of her

ſurface toward the north, and ſometimes the like toward the ſouth are viſible, which at other times are out of ſight. Theſe appearances make what is called the libration of the moon, diſcovered by HEVELIUS. But now as the axis of the oval figure of the waters will be pointed towards the earth, there muſt ariſe from hence ſome fluctuation in them; and beſide, by the change of the moon's diſtance from the earth, they will not always have the very ſame height.


J. Grison del.
J. Pine Sculp.

BOOK III.

Chap I.

Concerning the cauſe of COLOURS inherent in the LIGHT.

AFTER this view which has been taken of Sir Isaac Newton's mathematical principles of philoſophy, and the uſe he has made of them, in explaining the ſyſtem of the world, &c. the courſe of my deſign directs us to turn our eyes to that other philoſophical work, his treatiſe of Optics, in which we ſhall find our great author's inimitable genius diſcovering it ſelf no leſs, than in the former; nay perhaps even more, ſince this work gives as many inſtances of his ſingular force of reaſoning, and of his unbounded invention, though unaſſiſted in great meaſure by thoſe rules and general precepts, which facilitate the invention of mathematical theorems. Nor yet is this work inferior to the other in uſefulneſs; for as that has made known to us one great principle in nature, by which the celeſtial motions are continued, and by which the frame of each globe is preſerved; ſo does this point out to us another principle no leſs univerſal, upon which depends all thoſe operations in the ſmaller parts of matter, for whoſe ſake the greater frame of the univerſe is erected; all thoſe immenſe globes, with which the whole heavens are filled, being without doubt only deſign'd as ſo many convenient apartments for carrying on the more noble operations of nature in vegetation and animal life. Which ſingle conſideration gives abundant proof of the excellency of our author's choice, in applying himſelf carefully to examine the action between light and bodies, ſo neceſſary in all the varieties of theſe productions, that none of them can be ſucceſsfully promoted without the concurrence of heat in a greater or leſs degree.

2. 'Tis true, our author has not made ſo full a diſcovery of the principle, by which this mutual action between light and bodies is cauſed; as he has in relation to the power, by which the planets are kept in their courſes: yet he has led us to the very entrance upon it, and pointed out the path ſo plainly which muſt be followed to reach it; that one may

be bold to ſay, whenever mankind ſhall be bleſſed with this improvement of their knowledge, it will be derived ſo directly from the principles laid down by our author in this book, that the greateſt ſhare of the praiſe due to the diſcovery will belong to him.

3. In ſpeaking of the progreſs our author has made, I ſhall diſtinctly purſue three things, the two firſt relating to the colours of natural bodies: for in the firſt head ſhall be ſhewn, how thoſe colours are derived from the properties of the light itſelf; and in the ſecond upon what properties of the bodies they depend: but the third head of my diſcourſe ſhall treat of the action of bodies upon light in refracting, reflecting, and inflecting it.

4. The firſt of theſe, which ſhall be the buſineſs of the preſent chapter, is contained in this one propoſition: that the ſun's direct light is not uniform in reſpect of colour, not being diſpoſed in every part of it to excite the idea of whiteneſs, which the whole raiſes; but on the contrary is a compoſition of different kinds of rays, one ſort of which if alone would give the ſenſe of red, another of orange, a third of yellow, a fourth of green, a fifth of light blue, a ſixth of indigo, and a ſeventh of a violet purple; that all theſe rays together by the mixture of their ſenſations impreſs upon the organ of ſight the ſenſe of whiteneſs, though each ray always imprints there its own colour; and all the difference between the colours of bodies when viewed in open day light ariſes from this, that coloured bodies

do not reflect all the ſorts of rays falling upon them in equal plenty, but ſome ſorts much more copiouſly than others; the body appearing of that colour, of which the light coming from it is moſt compoſed.

5. THAT the light of the ſun is compounded, as has been ſaid, is proved by refracting it with a priſm. By a priſm I here mean a glaſs or other body of a triangular form, ſuch as is repreſented in fig. 121. But before we proceed to the illuſtration of the propoſition we have juſt now laid down, it will be neceſſary to ſpend a few words in explaining what is meant by the refraction of light; as the deſign of our preſent labour is to give ſome notion of the ſubject, we are engaged in, to ſuch as are not verſed in the mathematics.

6. IT is well known, that when a ray of light paſſing through the air falls obliquely upon the ſurface of any tranſparent body, ſuppoſe water or glaſs, and enters it, the ray will not paſs on in that body in the ſame line it deſcribed through the air, but be turned off from the ſurface, ſo as to be leſs inclined to it after paſſing it, than before. Let ABCD (in fig. 122.) repreſent a portion of water, or glaſs, AB the ſurface of it, upon which the ray of light EF falls obliquely; this ray ſhall not go right on in the courſe delineated by the line FG, but be turned off from the ſurface AB into the line FH, leſs inclined to the ſurface AB than the line EF is, in which the ray is incident upon that ſurface.

7. ON the other hand, when the light paſſes out of any ſuch body into the air, it is inflected the contrary way, being after its emergence rendred more oblique to the ſurface it paſſes through, than before. Thus the ray FH, when it goes out of the ſurface CD, will be turned up towards that ſurface, going out into the air in the line HI.

8. THIS turning of the light out of its way, as it paſſes from one tranſparent body into another is called its refraction. Both theſe caſes may be tried by an eaſy experiment with a baſon and water. For the firſt caſe ſet an empty baſon in the ſunſhine or near a candle, making a mark upon the bottom at the extremity of the ſhadow caſt by the brim of the baſon, then by pouring water into the baſon you will obſerve the ſhadow to ſhrink, and leave the bottom of the baſon enlightned to a good diſtance from the mark. Let ABC (in fig. 123.) denote the empty baſon, EAD the light ſhining over the brim of it, ſo that all the part ABD be ſhaded. Then a mark being made at D, if water be poured into the baſon (as in fig. 124.) to FG, you ſhall obſerve the light, which before went on to D, now to come much ſhort of the mark D, falling on the bottom in the point H, and leaving the mark D a good way within the enlightened part; which ſhews that the ray EA, when it enters the water at I, goes no longer ſtraight forwards, but is at that place incurvated, and made to go nearer the perpendicular. The other caſe may be tryed by putting any ſmall body into an empty baſon, placed lower than your eye, and then receding from the baſon, till you can but juſt

ſee the body over the brim. After which, if the baſon be filled with water, you ſhall preſently obſerve the body to be viſible, though you go farther off from the baſon. Let ABC (in fig. 125.) denote the baſon as before, D the body in it, E the place of your eye, when the body is ſeen juſt over the edge A, while the baſon is empty. If it be then filled with water, you will obſerve the body ſtill to be viſible, though you take your eye farther off. Suppoſe you ſee the body in this caſe juſt over the brim A, when your eye is at F, it is plain that the rays of light, which come from the body to your eye have not come ſtraight on, but are bent at A, being turned downwards, and more inclined to the ſurface of the water, between A and your eye at F, than they are between A and the body D.

9. THIS we hope is ſufficient to make all our readers apprehend, what the writers of optics mean, when they mention the refraction of the light, or ſpeak of the rays of light being refracted. We ſhall therefore now go on to prove the aſſertion advanced in the forementioned propoſition, in relation to the different kinds of colours, that the direct light of the ſun exhibits to our ſenſe: which may be done in the following manner.

10. IF a room be darkened, and the ſun permitted to ſhine into it through a ſmall hole in the window ſhutter, and be made immediately to fall upon a glaſs priſm, the beam of light ſhall in paſſing through ſuch a priſm be parted into rays, which exhibit all the forementioned colours. In this manner

ner if AB (in fig. 126) repreſent the window ſhutter; C the hole in it; DEF the priſm; ZY a beam of light coming from the ſun, which paſſes through the hole, and falls upon the priſm at Y, and if the priſm were removed would go on to X, but in entring the ſurface BF of the glaſs it ſhall be turned off, as has been explained, into the courſe YW falling upon the ſecond ſurface of the priſm DF in W, going out of which into the air it ſhall be again farther inflected. Let the light now, after it has paſſed the priſm, be received upon a ſheet of paper held at a proper diſtance, and it ſhall paint upon the paper the picture, image, or ſpectrum LM of an oblong figure, whoſe length ſhall much exceed its breadth; though the figure ſhall not be oval, the ends L and M being ſemicircular and the ſides ſtraight. But now this figure will be variegated with colours in this manner. From the extremity M to ſome length, ſuppoſe to the line *no*, it ſhall be of an intenſe red; from *no* to *pq* it ſhall be an orange; from *pq* to *rs* it ſhall be yellow; from thence to *tu* it ſhall be green; from thence to *wx* blue; from thence to *yz* indigo; and from thence to the end violet.

11. Thus it appears that the ſun's white light by its paſſage through the priſm, is ſo changed as now to be divided into rays, which exhibit all theſe ſeveral colours. The queſtion is, whether the rays while in the ſun's beam before this refraction poſſeſſed theſe properties diſtinctly; ſo that ſome part of that beam would without the reſt have given a red colour, and another part alone have given an orange,

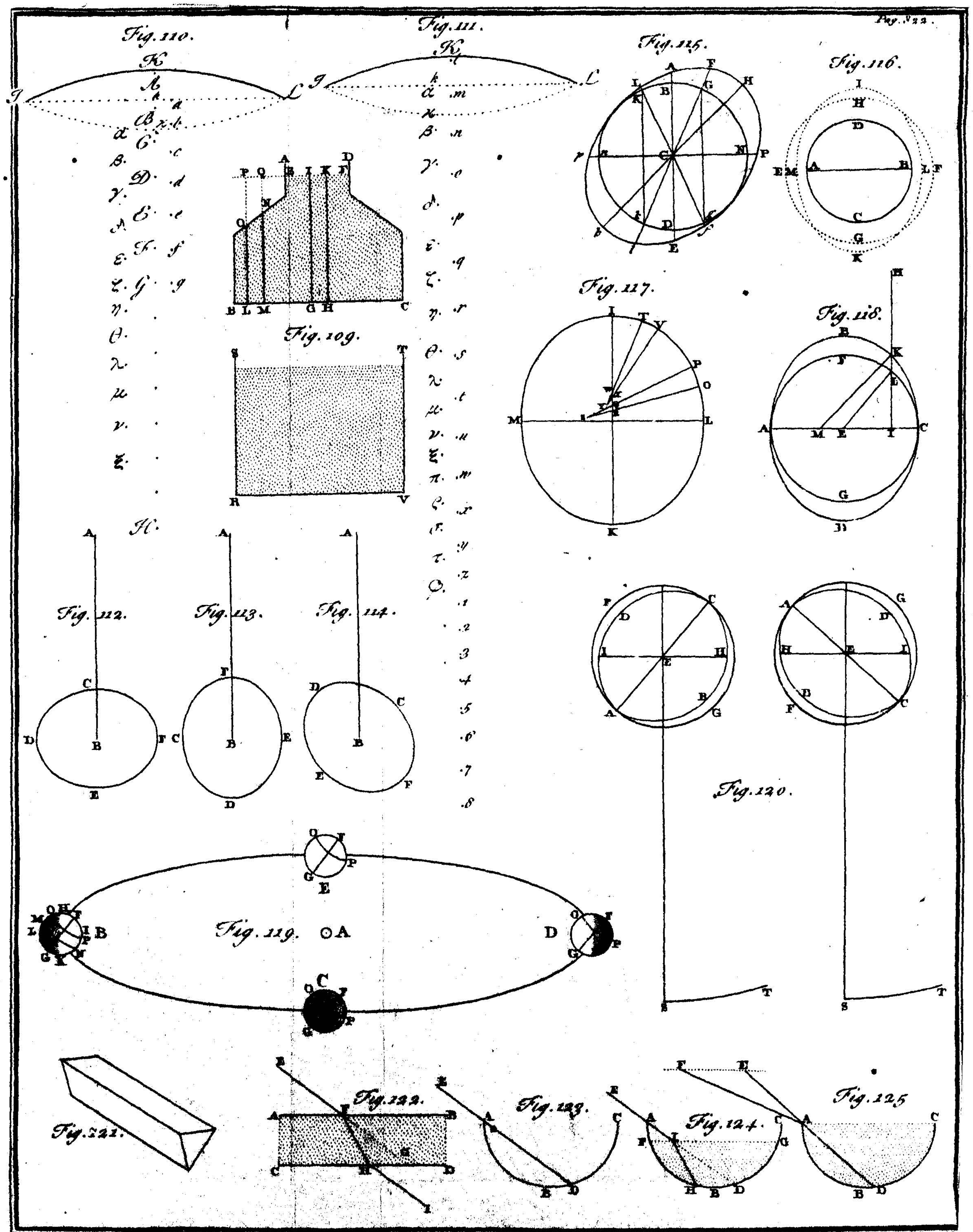


Fig. 110.
Fig. 111.
Fig. 115.
Fig. 116.
Fig. 109.
Fig. 117.
Fig. 118.
Fig. 112.
Fig. 113.
Fig. 114.
Fig. 120.
Fig. 119.
A
B
C
D
E
Fig. 121.
Fig. 122.
Fig. 123.
Fig. 124.
Fig. 125

orange, &c. That this is poſſible to be the caſe, appears from hence; that if a convex glaſs be placed between the paper and the priſm, which may collect all the rays proceeding out of the priſm into its focus, as a burning glaſs does the ſun's direct rays; and if that focus fall upon the paper, the ſpot formed by ſuch a glaſs upon the paper ſhall appear white, juſt like the ſun's direct light. The reſt remaining as before, let PQ (in fig. 127.) be the convex glaſs, cauſing the rays to meet upon the paper HGIK in the point N, I ſay that point or rather ſpot of light ſhall appear white, without the leaſt tincture of any colour. But it is evident that into this ſpot are now gathered all thoſe rays, which before when ſeparate gave all thoſe different colours; which ſhews that whiteneſs may be made by mixing thoſe colours: eſpecially if we conſider, it can be proved that the glaſs PQ does not alter the colour of the rays which paſs through it. Which is done thus: if the paper be made to approach the glaſs PQ, the colours will manifeſt themſelves as far as the magnitude of the ſpectrum, which the paper receives, will permit. Suppoſe it in the ſituation *hgik*, and that it then receive the ſpectrum *lm*, this ſpectrum ſhall be much ſmaller, than if the glaſs PQ were removed, and therefore the colours cannot be ſo much ſeparated; but yet the extremity *m* ſhall manifeſtly appear red, and the other extremity *l* ſhall be blue; and theſe colours as well as the intermediate ones ſhall diſcover themſelves more perfectly, the farther the paper is removed from N, that is, the larger the ſpectrum is: the ſame thing happens, if the paper be removed farther off from PQ than N. Suppoſe into the poſition θγηκ, the ſpectrum λμ painted upon it ſhall again diſcover its colours, and that more diſtinctly, the farther the paper is removed, but only in an inverted order: for as before, when the paper was nearer the convex glaſs, than at N, the upper part of the image was blue, and the under red; now the upper part ſhall be red, and the under blue; becauſe the rays croſs at N.

12. Nay farther that the whiteneſs at the focus N, is made by the union of the colours may be proved without removing the paper out of the focus, by intercepting with any opake body part of the light near the glaſs; for if the under part, that is the red, or more properly the red-making rays, as they are ſtyled by our author, are intercepted, the ſpot ſhall take a bluiſh hue; and if more of the inferior rays are cut off, ſo that neither the red-making nor orange-making rays, and if you pleaſe the yellow-making rays likewiſe, ſhall fall upon the ſpot; then ſhall the ſpot incline more and more to the remaining colours. In like manner if you cut off the upper part of the rays, that is the violet coloured or indigo-making rays, the ſpot ſhall turn reddiſh, and become more ſo, the more of thoſe oppoſite colours are intercepted

13. This I think abundantly proves that whiteneſs may be produced by a mixture of all the colours of the ſpectrum. At leaſt there is but one way of evading the preſent arguments, which is, by aſſerting that the rays of light after paſſing the priſm have no different properties to exhibit this or the other colour, but are in that reſpect per-

fectly homogeneal, ſo that the rays which paſs to the under and red part of the image do not differ in any properties whatever from thoſe, which go to the upper and violet part of it; but that the colours of the ſpectrum are produced only by ſome new modifications of the rays, made at their incidence upon the paper by the different terminations of light and ſhadow: if indeed this aſſertion can be allowed any place, after what has been ſaid; for it ſeems to be ſufficiently obviated by the latter part of the preceding experiment, that by intercepting the inferior part of the light, which comes from the priſm, the white ſpot ſhall receive a bluiſh caſt, and by ſtopping the upper part the ſpot ſhall turn red, and in both caſes recover its colour, when the intercepted light is permitted to paſs again; though in all theſe trials there is the like termination of light and ſhadow. However our author has contrived ſome experiments expreſly to ſhew the abſurdity of this ſuppoſition; all which he has explained and enlarged upon in ſo diſtinct and expreſſive a manner, that it would be wholly unneceſſary to repeat them in this place[a]. I ſhall only mention that of them, which may be tried in the experiment before us. If you draw upon the paper HGIK, and through the ſpot N, the ſtraight line *wx* parallel to the horizon, and then if the paper be much inclined into the ſituation *rsvt* the line *wx* ſtill remaining parallel to the horizon, the ſpot N ſhall loſe its whiteneſs and receive a blue tincture; but if it be inclined as much the contrary way, the ſame ſpot ſhall exchange its white colour for a reddiſh dye.

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[a] Opt. B. I. part 2. prop. 1.

All which can never be accounted for by any difference in the termination of the light and ſhadow, which here is none at all; but are eaſily explained by ſuppoſing the upper part of the rays, whenever they enter the eye, diſpoſed to give the ſenſation of the dark colours blue, indigo and violet; and that the under part is fitted to produce the bright colours yellow, orange and red: for when the paper is in the ſituation *rstu*, it is plain that the upper part of the light falls more directly upon it, than the under part, and therefore thoſe rays will be moſt plentifully reflected from it; and by their abounding in the reflected light will cauſe it to incline to their colour. Juſt ſo when the paper is inclined the contrary way, it will receive the inferior rays moſt directly, and therefore ting the light it reflects with their colour.

14. IT is now to be proved that theſe diſpoſitions of the rays of light to produce ſome one colour and ſome another, which manifeſt themſelves after their being refracted, are not wrought by any action of the priſm upon them, but are originally inherent in thoſe rays; and that the priſm only affords each ſpecies an occaſion of ſhewing its diſtinct quality by ſeparating them one from another, which before, while they were blended together in the direct beam of the ſun's light, lay conceal'd. But that this is ſo, will be proved, if it can be ſhewn that no priſm has any power upon the rays, which after their paſſage through one priſm are rendered uncompounded and contain in them but one colour, either to divide that colour into ſeveral, as the ſun's

light is divided, or ſo much as to change it into any other colour. This will be proved by the following experiment[a]. The ſame thing remaining, as in the firſt experiment, let another priſm NO (in fig. 128.) be placed either immediately, or at ſome diſtance after the firſt, in a perpendicular poſture, ſo that it ſhall refract the rays iſſuing from the firſt ſideways. Now if this priſm could divide the light falling upon it into coloured rays, as the firſt has done, it would divide the ſpectrum breadthwiſe into colours, as before it was divided lengthwiſe; but no ſuch thing is obſerved. If LM were the ſpectrum, which the firſt priſm DEF would paint upon the paper HGIK; PQ lying in an oblique poſture ſhall be the ſpectrum projected by the ſecond, and ſhall be divided lengthwiſe into colours correſponding to the colours of the ſpectrum LM, and occaſioned like them by the refraction of the firſt priſm, but its breadth ſhall receive no ſuch diviſion; on the contrary each colour ſhall be uniform from ſide to ſide, as much as in the ſpectrum LM, which proves the whole aſſertion.

15. THE ſame is yet much farther confirmed by another experiment. Our author teaches that the colours of the ſpectrum LM in the firſt experiment are yet compounded, though not ſo much as in the ſun's direct light. He ſhews therefore how, by placing the priſm at a diſtance from the hole, and by the uſe of a convex glaſs, to ſeparate the colours of the ſpectrum, and make them uncompounded to any degree of exactneſs[b]. And he ſhews when this

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[a] Newt. Opt. B. 1. part 1. experim. 5.

[b] Ibid prop. 4.

is done ſufficiently, if you make a ſmall hole in the paper whereon the ſpectrum is received, through which any one ſort of rays may paſs, and then let that coloured ray fall ſo upon a priſm, as to be refracted by it, it ſhall in no caſe whatever change its colour; but ſhall always retain it perfectly as at firſt, however it be refracted [a].

16. NOR yet will theſe colours after this full ſeparation of them ſuffer any change by reflection from bodies of different colours; on the other hand they make all bodies placed in theſe colours appear of the colour which falls upon them [b]: for minium in red light will appear as in open day light; but in yellow light will appear yellow; and which is more extraordinary, in green light will appear green, in blue, blue; and in the violet-purple coloured light will appear of a purple colour; in like manner verdigreaſe, or blue biſe, will put on the appearance of that colour, in which it is placed: ſo that neither biſe placed in the red light ſhall be able to give that light the leaſt blue tincture, or any other different from red; nor ſhall minium in the indigo or violet light exhibit the leaſt appearance of red, or any other colour diſtinct from that it is placed in. The only difference is, that each of theſe bodies appears moſt luminous and bright in the colour, which correſponds with that it exhibits in the day light, and dimmeſt in the colours moſt remote from that; that is, though minium and biſe placed in blue light ſhall both appear blue, yet the biſe ſhall appear of a bright blue, and the minium of a dusky and obſcure blue: but

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[a] Newt. Opt. B. 1. part 2. exper. 5.

[b] Ibid exper. 6.

if minium and biſe be compared together in red light, the minium ſhall afford a briſk red, the biſe a duller colour, though of the ſame ſpecies.

17. And this not only proves the immutability of all theſe ſimple and uncompounded colours; but likewiſe unfolds the whole myſtery, why bodies appear in open day-light of ſuch different colours, it conſiſting in nothing more than this, that whereas the white light of the day is compoſed of all ſorts of colours, ſome bodies reflect the rays of one ſort in greater abundance than the rays of any other [a]. Though it appears by the forecited experiment, that almoſt all theſe bodies reflect ſome portion of the rays of every colour, and give the ſenſe of particular colours only by the predominancy of ſome ſorts of rays above the reſt. And what has before been explained of compoſing white by mingling all the colours of the ſpectrum together ſhews clearly, that nothing more is required to make bodies look white, than a power to reflect indifferently rays of every colour. But this will more fully appear by the following method: if near the coloured ſpectrum in our firſt experiment a piece of white paper be ſo held, as to be illuminated equally by all the parts of that ſpectrum, it ſhall appear white; whereas if it be held nearer to the red end of the image, than to the other, it ſhall turn reddiſh; if nearer the blue end, it ſhall ſeem bluiſh [b].

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[a] Newton Opt. B. I. prop. 10. [b] Ibid exp. 9.

18. OUR indefatigable and circumſpect author farther examined his theory by mixing the powders which painters uſe of ſeveral colours, in order if poſſible to produce a white powder by ſuch a compoſition [a]. But in this he found ſome difficulties for the following reaſons. Each of theſe coloured powders reflects but part of the light, which is caſt upon them; the red powders reflecting little green or blue, and the blue powders reflecting very little red or yellow, nor the green powders reflecting near ſo much of the red or indigo and purple, as of the other colours: and beſides, when any of theſe are examined in homogeneal light, as our author calls the colours of the priſm, when well ſeparated, though each appears more bright and luminous in its own day-light colour, than in any other; yet white bodies, ſuppoſe white paper for inſtance, in thoſe very colours exceed theſe coloured bodies themſelves in brightneſs; ſo that white bodies reflect not only more of the whole light than coloured bodies do in the day-light, but even more of that very colour which they reflect moſt copiouſly. All which conſiderations make it manifeſt that a mixture of theſe will not reflect ſo great a quantity of light, as a white body of the ſame ſize; and therefore will compoſe ſuch a colour as would reſult from a mixture of white and black, ſuch as are all grey and dun colours, rather than a ſtrong white. Now ſuch a colour he compounded of certain ingredients, which he particularly ſets down, in ſo much that when the compoſition was ſtrongly illuminated by the ſun's direct beams, it would appear much whiter than even white pa-

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[a] Newt. Opt. B. I. part 1. exp. 15.

per, if conſiderably ſhaded. Nay he found by trials how to proportion the degree of illumination of the mixture and paper, ſo that to a ſpectator at a proper diſtance it could not well be determined which was the more perfect colour; as he experienced not only by himſelf, but by the concurrent opinion of a friend, who chanced to viſit him while he was trying this experiment. I muſt not here omit another method of trying the whiteneſs of ſuch a mixture, propoſed in one of our author's letters on this ſubject [a]: which is to enlighten the compoſition by a beam of the ſun let into a darkened room, and then to receive the light reflected from it upon a piece of white paper, obſerving whether the paper appears white by that reflection; for if it does, it gives proof of the compoſition's being white; becauſe when the paper receives the reflection from any coloured body, it looks of that colour. Agreeable to this is the trial he made upon water impregnated with ſoap, and agitated into a froth [b]: for when this froth after ſome ſhort time exhibited upon the little bubbles, which compoſed it, a great variety of colours, though theſe colours to a ſpectator at a ſmall diſtance diſcover'd themſelves diſtinctly; yet when the eye was ſo far removed, that each little bubble could no longer be diſtinguiſhed, the whole froth by the mixture of all theſe colours appeared intenſly white.

19. OUR author having fully ſatisfied himſelf by theſe and many other experiments, what the reſult is of mixing

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[a] Philoſ. Tranſact. N. 88, p. 5099.

[b] Opt. B. I. par. 2. exp. 14.

together all the priſmatic colours; he proceeds in the next place to examine, whether this appearance of whiteneſs be raiſed by the rays of theſe different kinds acting ſo, when they meet, upon one another, as to cauſe each of them to impreſs the ſenſe of whiteneſs upon the optic nerve; or whether each ray does not make upon the organ of ſight the ſame impreſſion, as when ſeparate and alone; ſo that the idea of whiteneſs is not excited by the impreſſion from any one part of the rays, but reſults from the mixture of all thoſe different ſenſations. And that the latter ſentiment is the true one, he evinces by undeniable experiments.

20. IN particular the foregoing experiment[a], wherein the convex glaſs was uſed, furniſhes proofs of this: in that when the paper is brought into the ſituation $\theta\gamma$, beyond N the colours, that at N diſappeared, begin to emerge again; which ſhews that by mingling at N they did not loſe their colorific qualities, though for ſome reaſon they lay concealed. This farther appears by that part of the experiment, when the paper, while in the focus, was directed to be enclined different ways; for when the paper was in ſuch a ſituation, that it muſt of neceſſity reflect the rays, which before their arrival at the point N would have given a blue colour, thoſe rays in this very point itſelf by abounding in the reflected light tinged it with the ſame colour; ſo when the paper reflects moſt copiouſly the rays, which before they come to the point N exhibit redneſs, thoſe ſame rays tin-

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[a] Ibid. exp. 10.

cture the light reflected by the paper from that very point with their own proper colour.

21. THERE is a certain condition relating to ſight, which affords an opportunity of examining this ſtill more fully: it is this, that the impreſſions of light remain ſome ſhort ſpace upon the eye; as when a burning coal is whirl'd about in a circle, if the motion be very quick, the eye ſhall not be able to diſtinguiſh the coal, but ſhall ſee an entire circle of fire. The reaſon of which appearance is, that the impreſſion made by the coal upon the eye in any one ſituation is not worn out before the coal returns again to the ſame place, and renews the ſenſation. This gives our author the hint to try, whether theſe colours might not be tranſmitted ſucceſſively to the eye ſo quick, that no one of the colours ſhould be diſtinctly perceived, but the mixture of the ſenſations ſhould produce a uniform whiteneſs; when the rays could not act upon each other, becauſe they never ſhould meet, but come to the eye one after another. And this thought he executed by the following expedient [a]. He made an inſtrument in ſhape like a comb, which he applied near the convex glaſs, ſo that by moving it up and down ſlowly the teeth of it might intercept ſometimes one and ſometimes another colour; and accordingly the light reflected from the paper, placed at N, ſhould change colour continually. But now when the comb-like inſtrument was moved very quick, the eye loſt all preception of the diſtinct colours, which came to it from time to time, a perfect whiteneſs reſulting from the

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[a] Opt. pag. 122.

mixture of all thoſe diſtinct impreſſions in the ſenſorium. Now in this caſe there can be no ſuſpicion of the ſeveral coloured rays acting upon one another, and making any change in each other's manner of affecting the eye, ſeeing they do not ſo much as meet together there.

22. Our author farther teaches us how to view the ſpectrum of colours produced in the firſt experiment with another priſm, ſo that it ſhall appear to the eye under the ſhape of a round ſpot and perfectly white[a]. And in this caſe if the comb be uſed to intercept alternately ſome of the colours, which compoſe the ſpectrum, the round ſpot ſhall change its colour according to the colours intercepted; but if the comb be moved too ſwiftly for thoſe changes to be diſtinctly perceived, the ſpot ſhall ſeem always white as before[b].

23. Besides this whiteneſs, which reſults from an univerſal compoſition of all ſorts of colours, our author particularly explains the effects of other leſs compounded mixtures; ſome of which compound other colours like ſome of the ſimple ones, but others produce colours different from any of them. For inſtance, a mixture of red and yellow compound a colour like in appearance to the orange, which in the ſpectrum lies between them; as a compoſition of yellow and blue is made uſe of in all dyes to make a green. But red and violet purple compounded make purples unlike to any of the priſmatic colours, and theſe joined with

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[a] Opt. B. I. part 2. exp. 11.

[b] Ibid prop. 4, 6.

yellow or blue make yet new colours. Beſides one rule is here to be obſerved, that when many different colours are mixed, the colour which ariſes from the mixture grows languid and degenerates into whiteneſs. So when yellow green and blue are mixed together, the compound will be green; but if to this you add red and purple, the colour ſhall firſt grow dull and leſs vivid, and at length by adding more of theſe colours it ſhall turn to whiteneſs, or ſome other colour [a].

24. ONLY here is one thing remarkable of thoſe compounded colours, which are like in appearance to the ſimple ones; that the ſimple ones when viewed through a priſm ſhall ſtill retain their colour, but the compounded colours ſeen through ſuch a glaſs ſhall be parted into the ſimple ones of which they are the aggregate. And for this reaſon any body illuminated by the ſimple light ſhall appear through a priſm diſtinctly, and have its minuteſt parts obſervable, as may eaſily be tried with flies, or other ſuch little bodies, which have very ſmall parts; but the ſame viewed in this manner when enlighten'd with compounded colours ſhall appear confuſed, their ſmalleſt parts not being diſtinguiſhable. How the priſm ſeparates theſe compounded colours, as likewiſe how it divides the light of the ſun into its colours, has not yet been explained; but is reſerved for our third chapter.

25. IN the mean time what has been ſaid, I hope, will ſuffice to give a taſte of our author's way of arguing, and

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[a] Opt. pag. 51.

in ſome meaſure to illuſtrate the propoſition laid down in this chapter.

26. THERE are methods of ſeparating the heterogeneous rays of the ſun's light by reflection, which perfectly conſpire with and confirm this reaſoning. One of which ways may be this. Let AB (in fig. 129) repreſent the window ſhutter of a darkened room; C a hole to let in the ſun's rays; DEF, GHI two priſms ſo applied together, that the ſides EF and GI be contiguous, and the ſides DF, GH parallel; by this means the light will paſs through them without any ſeparation into colours: but if it be afterwards received by a third priſm IKL, it ſhall be divided ſo as to form upon any white body PQ the uſual colours, violet at *m*, blue at *n*, green at *o*, yellow at *r*, and red at *s*. But becauſe it never happens that the two adjacent ſurfaces EF and GI perfectly touch, part only of the light incident upon the ſurface EF ſhall be tranſmitted, and part ſhall be reflected. Let now the reflected part be received by a fourth priſm ΔΘΛ, and paſſing through it paint upon a white body ZΓ the colours of the priſm, red at *t*, yellow at *u*, green at *w*, blue at *x*, violet at *y*. If the priſms DEF, GHI be ſlowly turned about while they remain contiguous, the colours upon the body PQ ſhall not ſenſibly change their ſituation, till ſuch time as the rays become pretty oblique to the ſurface EF; but then the light incident upon the ſurface EF ſhall begin to be wholly reflected. And firſt of all the violet light ſhall be wholly reflected, and thereupon will diſappear at *m*, appearing inſtead thereof

at *y*, and increaſing the violet light falling there, the other colours remaining as before. If the priſms DEF, GHI be turned a little farther about, that the incident rays become yet more inclined to the ſurface EF, the blue ſhall be totally reflected, and ſhall diſappear in *n*, but appear at *x* by making the colour there more intenſe. And the ſame may be continued, till all the colours are ſucceſſively removed from the ſurface PQ to Zr. But in any caſe, ſuppoſe when the violet and the blue have forſaken the ſurface PQ, and appear upon the ſurface Zr, the green, yellow, and red only remaining upon the ſurface PQ; if the light be received upon a paper held any where in its whole paſſage between the light's coming out of the priſms DEF, GIH and its incidence upon the priſm IKL, it ſhall appear of the colour compounded of all the colours ſeen upon PQ; and the reflected ray, received upon a piece of white paper held any where between the priſms DEF and ΔΘΣ, ſhall exhibit the colour compounded of thoſe the ſurface PQ is deprived of mixed with the ſun's light: whereas before any of the light was reflected from the ſurface EF, the rays between the priſms GHI and IKL would appear white; as will likewiſe the reflected ray both before and after the total reflection, provided the difference of refraction by the ſurfaces DF and DE be inconſiderable. I call here the ſun's light white, as I have all along done; but it is more exact to aſcribe to it ſomething of a yellowiſh tincture, occaſioned by the brighter colours abounding in it; which caution is neceſſary in examining the colours of the reflected beam, when all the violet and blue are in it: for this yellowiſh turn of the ſun's light cauſes the blue not to be quite ſo viſible in it, as it ſhould be, were the light perfectly white; but makes the beam of light incline rather towards a pale white.

CHAP. II.

Of the properties of BODIES, upon which their COLOURS depend.

AFTER having ſhewn in the laſt chapter, that the difference between the colours of bodies viewed in open day-light is only this, that ſome bodies are diſpoſed to reflect rays of one colour in the greateſt plenty, and other bodies rays of ſome other colour; order now requires us to examine more particularly into the property of bodies, which gives them this difference. But this our author ſhews to be nothing more, than the different magnitude of the particles, which compoſe each body: this I queſtion not will appear no ſmall paradox. And indeed this whole chapter will contain ſcarce any aſſertions, but what will be almoſt incredible, though the arguments for them are ſo ſtrong and convincing, that they force our aſſent. In the former chapter have been explained properties of light, not in the leaſt thought of before our author's diſcovery of them; yet are they not difficult to admit, as ſoon as experiments are known to give proof of their reality; but ſome of the propoſitions to be ſtated here will, I fear, be accounted almoſt paſt belief; notwithſtanding that the arguments, by which they are eſtabliſhed are unanſwerable. For it is proved by our author, that bodies are rendered tranſparent by the minuteneſs of their pores, and become opake by having them large; and more, that the moſt tranſparent body by being reduced to a great thinneſs will become leſs pervious to the light.

2. BUT whereas it had been the received opinion, and yet remains ſo among all who have not ſtudied this philoſophy, that light is reflected from bodies by its impinging againſt their ſolid parts, rebounding from them, as a tennis ball or other elaſtic ſubſtance would do, when ſtruck againſt any hard and reſiſting ſurface; it will be proper to begin with declaring our author's ſentiment concerning this, who ſhews by many arguments that reflection cannot be cauſed by any ſuch means[a]: ſome few of his proofs I ſhall ſet down, referring the reader to our author himſelf for the reſt.

3. IT is well known, that when light falls upon any tranſparent body, glaſs for inſtance, part of it is reflected and part tranſmitted; for which it is ready to account, by ſaying that part of the light enters the pores of the glaſs, and part impinges upon its ſolid parts. But when the tranſmitted light arrives at the farther ſurface of the glaſs, in paſſing out of glaſs into air there is as ſtrong a reflection cauſed, or rather ſomething ſtronger. Now it is not to be conceived, how the light ſhould find as many ſolid parts in the air to ſtrike againſt as in the glaſs, or even a greater num-

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[a] *Opt.* Book II. *prop.* 8.

ber of them. And to augment the difficulty, if water be placed behind the glaſs, the reflection becomes much weaker. Can we therefore ſay, that water has fewer ſolid parts for the light to ſtrike againſt, than the air? And if we ſhould, what reaſon can be given for the reflection's being ſtronger, when the air by the air-pump is removed from behind the glaſs, than when the air receives the rays of light. Beſides the light may be ſo inclined to the hinder ſurface of the glaſs, that it ſhall wholly be reflected, which happens when the angle which the ray makes with the ſurface does not exceed about $49\frac{1}{3}$ degrees; but if the inclination be a very little increaſed, great part of the light will be tranſmitted; and how the light in one caſe ſhould meet with nothing but the ſolid parts of the air, and by ſo ſmall a change of its inclination find pores in great plenty, is wholly inconceivable. It cannot be ſaid, that the light is reflected by ſtriking againſt the ſolid parts of the ſurface of the glaſs; becauſe without making any change in that ſurface, only by placing water contiguous to it inſtead of air, great part of that light ſhall be tranſmitted, which could find no paſſage through the air. Moreover in the laſt experiment recited in the preceding chapter, when by turning the priſms DEF, GHI, the blue light became wholly reflected, while the reſt was moſtly tranſmitted, no poſſible reaſon can be aſſigned, why the blue-making rays ſhould meet with nothing but the ſolid parts of the air between the priſms, and the reſt of the light in the very ſame obliquity find pores in abundance. Nay farther, when two glaſſes touch each other, no reflection at all is made; though it does not in the leaſt appear, how the rays ſhould avoid the ſolid parts of glaſs, when contiguous to other glaſs, any more than when contiguous to air. But in the laſt place upon this ſuppoſition it is not to be comprehended, how the moſt poliſhed ſubſtances could reflect the light in that regular manner we find they do; for when a poliſhed looking glaſs is covered over with quick ſilver, we cannot ſuppoſe the particles of light ſo much larger than thoſe of the quickſilver, that they ſhould not be ſcattered as much in reflection, as a parcel of marbles thrown down upon a rugged pavement. The only cauſe of ſo uniform and regular a reflection muſt be ſome more ſecret cauſe, uniformly ſpread over the whole ſurface of the glaſs.

4. BUT now, ſince the reflection of light from bodies does not depend upon its impinging againſt their ſolid parts, ſome other reaſon muſt be ſought for. And firſt it is paſt doubt that the leaſt parts of almoſt all bodies are tranſparent, even the microſcope ſhewing as much [a]; beſides that it may be experienced by this method. Take any thin plate of the opakeſt body, and apply it to a ſmall hole deſigned for the admiſſion of light into a darkened room; however opake that body may ſeem in open day-light, it ſhall under theſe circumſtances ſufficiently diſcover its tranſparency, provided only the body be very thin. White metals indeed do not eaſily ſhew themſelves tranſparent in theſe trials, they reflecting almoſt all the light incident upon them at their firſt ſuperficies; the cauſe of which will appear in what

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[a] Opt. Book II. par. 3. prop. 2.

follows[a]. But yet theſe ſubſtances, when reduced into parts of extraordinary minuteneſs by being diſſolved in aqua fortis or the like corroding liquors do alſo become tranſparent.

5. Since therefore the light finds free paſſage through the leaſt parts of bodies, let us conſider the largeneſs of their pores, and we ſhall find, that whenever a ray of light has paſſed through any particle of a body, and is come to its farther ſurface, if it finds there another particle contiguous, it will without interruption paſs into that particle; juſt as light will paſs through one piece of glaſs into another piece in contact with it without any impediment, or any part being reflected: but as the light in paſſing out of glaſs, or any other tranſparent body, ſhall part of it be reflected back, if it enter into air or other tranſparent body of a different denſity from that it paſſes out of; the ſame thing will happen in the light's paſſage through any particle of a body, whenever at its exit out of that particle it meets no other particle contiguous, but muſt enter into a pore, for in this caſe it ſhall not all paſs through, but part of it be reflected back. Thus will the light, every time it enters a pore, be in part reflected; ſo that nothing more ſeems neceſſary to opacity, than that the particles, which compoſe any body, touch but in very few places, and that the pores of it are numerous and large, ſo that the light may in part be reflected from it, and the other part, which enters too deep to be returned out of the body, by numerous reflections may be ſtifled and loſt[b]; which in all probabi-

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[a] § 17.

[b] Opt. Book II. par. 3. prop. 4.

lity happens, as often as it impinges againſt the ſolid part of the body, all the light which does ſo not being reflected back, but ſtopt, and deprived of any farther motion [a].

6. THIS notion of opacity is greatly confirmed by the obſervation, that opake bodies become tranſparent by filling up the pores with any ſubſtance of near the ſame denſity with their parts. As when paper is wet with water or oyl; when linnen cloth is either dipt in water, oyled, or varniſhed; or the oculus mundi ſtone ſteeped in water [b]. All which experiments confirm both the firſt aſſertion, that light is not reflected by ſtriking upon the ſolid parts of bodies; and alſo the ſecond, that its paſſage is obſtructed by the reflections it undergoes in the pores; ſince we find it in theſe trials to paſs in greater abundance through bodies, when the number of their ſolid parts is increaſed, only by taking away in great meaſure thoſe reflections; which filling the pores with a ſubſtance of near the ſame denſity with the parts of the body will do. Beſides as filling the pores of a dark body makes it tranſparent; ſo on the other hand evacuating the pores of a body tranſparent, or ſeparating the parts of ſuch a body, renders it opake. As ſalts or wet paper by being dried, glaſs by being reduced to powder or the ſurface made rough; and it is well known that glaſs veſſels diſcover cracks in them by their opacity. Juſt ſo water itſelf becomes impervious to the light by being formed into many ſmall bubbles, whether in froth, or by being mixed and agitated with any quantity of a liquor

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[a] Opt. Book II. pag. 241.

[b] Ibid. pag. 224.

with which it will not incorporate, ſuch as oyl of turpentine, or oyl olive.

7. A CERTAIN electrical experiment made by Mr. HAUKSBEE may not perhaps be uſeleſs to clear up the preſent ſpeculation, by ſhewing that ſomething more is neceſſary beſides mere poroſity for tranſmitting freely other fine ſubſtances. The experiment is this; that a glaſs cane rubbed till it put forth its electric quality would agitate leaf braſs incloſed under a glaſs veſſel, though not at ſo great a diſtance, as if no body had intervened; yet the ſame cane would loſe all its influence on the leaf braſs by the interpoſition of a piece of the fineſt muſlin, whoſe pores are immenſely larger and more patent than thoſe of glaſs.

8. THUS I have endeavoured to ſmooth my way, as much as I could, to the unfolding yet greater ſecrets in nature; for I ſhall now proceed to ſhew the reaſon why bodies appear of different colours. My reader no doubt will be ſufficiently ſurprized, when I inform him that the knowledge of this is deduced from that ludicrous experiment, with which children divert themſelves in blowing bubbles of water made tenacious by the ſolution of ſoap. And that theſe bubbles, as they gradually grow thinner and thinner till they break, change ſucceſſively their colours from the ſame principle, as all natural bodies preſerve theirs.

9. OUR author after preparing water with ſoap, ſo as to render it very tenacious, blew it up into a bubble, and plac-

ing it under a glaſs, that it might not be irregularly agitated by the air, obſerved as the water by ſubſiding changed the thickneſs of the bubble, making it gradually leſs and leſs till the bubble broke; there ſucceſſively appeared colours at the top of the bubble, which ſpread themſelves into rings ſurrounding the top and deſcending more and more, till they vaniſhed at the bottom in the ſame order in which they appeared [a]. The colours emerged in this order: firſt red, then blue; to which ſucceeded red a ſecond time, and blue immediately followed; after that red a third time, ſucceeded by blue; to which followed a fourth red, but ſucceeded by green; after this a more numerous order of colours, firſt red, then yellow, next green, and after that blue, and at laſt purple; then again red, yellow, green, blue, violet followed each other in order; and in the laſt place red, yellow, white, blue; to which ſucceeded a dark ſpot, which reflected ſcarce any light, though our author found it did make ſome very obſcure reflection, for the image of the ſun or a candle might be faintly diſcerned upon it; and this laſt ſpot ſpread itſelf more and more, till the bubble at laſt broke. Theſe colours were not ſimple and uncompounded colours, like thoſe which are exhibited by the priſm, when due care is taken to ſeparate them; but were made by a various mixture of thoſe ſimple colours, as will be ſhewn in the next chapter: whence theſe colours, to which I have given the name of blue, green, or red, were not all alike, but differed as follows. The blue, which appeared next the dark ſpot, was a pure colour, but very faint, reſembling the ſky-colour; the white next to it a very ſtrong and intenſe white, brighter much than the white, which the bubble reflected, before any of the colours appeared. The yellow which preceded this was at firſt pretty good, but ſoon grew dilute; and the red which went before the yellow at firſt gave a tincture of ſcarlet inclining to violet, but ſoon changed into a brighter colour; the violet of the next ſeries was deep with little or no redneſs in it; the blue a brisk colour, but came much ſhort of the blue in the next order; the green was but dilute and pale; the yellow and red were very bright and full, the beſt of all the yellows which appeared among any of the colours: in the preceding orders the purple was reddiſh, but the blue, as was juſt now ſaid, the brighteſt of all; the green pretty lively better than in the order which appeared before it, though that was a good willow green; the yellow but ſmall in quantity, though bright; the red of this order not very pure: thoſe which appeared before yet more obſcure, being very dilute and dirty; as were likewiſe the three firſt blues.

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[a] Ibid. Obſ. 17. &c.

10. Now it is evident, that theſe colours aroſe at the top of the bubble, as it grew by degrees thinner and thinner: but what the expreſs thickneſs of the bubble was, where each of theſe colours appeared upon it, could not be determined by theſe experiments; but was found by another means, viz. by taking the object glaſs of a long teleſcope, which is in a ſmall degree convex, and placing it upon a flat glaſs, ſo as to touch it in one point, and then water being put between them, the ſame colours appeared as in the

bubble, in the form of circles or rings ſurrounding the point where the glaſſes touched, which appeared black for want of any reflection from it, like the top of the bubble when thinneſt[a]: next to this ſpot lay a blue circle, and next without that a white one; and ſo on in the ſame order as before, reckoning from the dark ſpot. And henceforward I ſhall ſpeak of each colour, as being of the firſt, ſecond, or any following order, as it is the firſt, ſecond, or any following one, counting from the black ſpot in the center of theſe rings; which is contrary to the order in which I muſt have mentioned them, if I ſhould have reputed them the firſt, ſecond, or third, &c. in order, as they ariſe after one another upon the top of the bubble.

11. BUT now by meaſuring the diameters of each of theſe rings, and knowing the convexity of the teleſcope glaſs, the thickneſs of the water at each of thoſe rings may be determined with great exactneſs: for inſtance the thickneſs of it, where the white light of the firſt order is reflected, is about $3\frac{7}{8}$ ſuch parts, of which an inch contains 1000000[b]. And this meaſure gives the thickneſs of the bubble, where it appeared of this white colour, as well as of the water between the glaſſes; though the tranſparent body which ſurrounds the water in theſe two caſes be very different: for our author found, that the condition of the ambient body would not alter the ſpecies of the colour at all, though it might its ſtrength and brightneſs; for pieces of Muſcovy glaſs, which were ſo thin as to appear coloured by being

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[a] Ibid. Obſ. 10. [b] Ibid. pag. 206.

wet with water, would have their colours faded and made leſs bright thereby; but he could not obſerve their ſpecies at all to be changed. So that the thickneſs of any tranſparent body determines its colour, whatever body the light paſſes through in coming to it[a].

12. BUT it was found that different tranſparent bodies would not under the ſame thickneſſes exhibit the ſame colours: for if the forementioned glaſſes were laid upon each other without any water between their ſurfaces, the air itſelf would afford the ſame colours as the water, but more expanded, inſomuch that each ring had a larger diameter, and all in the ſame proportion. So that the thickneſs of the air proper to each colour was in the ſame proportion larger, than the thickneſs of the water appropriated to the ſame[b].

13. IF we examine with care all the circumſtances of theſe colours, which will be enumerated in the next chapter, we ſhall not be ſurprized, that our author takes them to bear a great analogy to the colours of natural bodies[c]. For the regularity of thoſe various and ſtrange appearances relating to them, which makes the moſt myſterious part of the action between light and bodies, as the next chapter will ſhew, is ſufficient to convince us that the principle, from which they flow, is of the greateſt importance in the frame of nature; and therefore without queſtion is deſigned for no leſs a purpoſe than to give bodies their various colours, to which end it ſeems very fitly ſuited. For if any ſuch tranſ-

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[a] Obſer. 21.

[b] Obſerv. 5. compared with Obſerv. 10.

[c] Ibid. prop. 5.

parent ſubſtance of the thickneſs proper to produce any one colour ſhould be cut into ſlender threads, or broken into fragments, it does not appear but theſe ſhould retain the ſame colour; and a heap of ſuch fragments ſhould frame a body of that colour. So that this is without diſpute the cauſe why bodies are of this or the other colour, that the particles of which they are compoſed are of different ſizes. Which is farther confirmed by the analogy between the colours of thin plates, and the colours of many bodies. For example, theſe plates do not look of the ſame colour when viewed obliquely, as when ſeen direct; for if the rings and colours between a convex and plane glaſs are viewed firſt in a direct manner, and then at different degrees of obliquity, the rings will be obſerved to dilate themſelves more and more as the obliquity is increaſed [a]; which ſhews that the tranſparent ſubſtance between the glaſſes does not exhibit the ſame colour at the ſame thickneſs in all ſituations of the eye: juſt ſo the colours in the very ſame part of a peacock's tail change, as the tail changes poſture in reſpect of the ſight. Alſo the colours of ſilks, cloths, and other ſubſtances, which water or oyl can intimately penetrate, become faint and dull by the bodies being wet with ſuch fluids, and recover their brightneſs again when dry; juſt as it was before ſaid that plates of Muſcovy glaſs grew faint and dim by wetting. To this may be added, that the colours which painters uſe will be a little changed by being ground very elaborately, without queſtion by the diminution of their parts. All which particulars, and many more that might be extracted from our author, give abundant proof of the preſent point. I ſhall only ſubjoin one more: theſe tranſparent plates tranſmit through them all the light they do not reflect; ſo that when looked through they exhibit thoſe colours, which reſult from the depriving white light of the colour reflected. This may commodiouſly be tryed by the glaſſes ſo often mentioned; which if looked through exhibit coloured rings as by reflected light, but in a contrary order; for the middle ſpot, which in the other view appears black for want of reflected light, now looks perfectly white, oppoſite to the blue circle; next without this ſpot the light appears tinged with a yellowiſh red; where the white circle appeared before, it now ſeems dark; and ſo of the reſt[a]. Now in the ſame manner, the light tranſmitted through foliated gold into a darkened room appears greeniſh by the loſs of the yellow light, which gold reflects.

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[a] Obſerv. 7.

14. HENCE it follows, that the colours of bodies give a very probable ground for making conjecture concerning the magnitude of their conſtituent particles[b]. My reaſon for calling it a conjecture is, its being difficult to fix certainly the order of any colour. The green of vegetables our author judges to be of the third order, partly becauſe of the intenſeneſs of their colour; and partly from the changes they ſuffer when they wither, turning at firſt into a greeniſh or more perfect yellow, and afterwards ſome of them to an orange or red; which changes ſeem to be effected from their tinging particles growing denſer by the exhalation of their

[a] Obſerv. 9. [b] Ibid prop. 7.

moiſture

moiſture, and perhaps augmented likewiſe by the accretion of the earthy and oily parts of that moiſture. How the mentioned colours ſhould ariſe from increaſing the bulk of thoſe particles, is evident; ſeeing thoſe colours lie without the ring of green between the glaſſes, and are therefore formed where the tranſparent ſubſtance which reflects them is thicker. And that the augmentation of the denſity of the colorific particles will conſpire to the production of the ſame effect, will be evident; if we remember what was ſaid of the different ſize of the rings, when air was included between the glaſſes, from their ſize when water was between them; which ſhewed that a ſubſtance of a greater denſity than another gives the ſame colour at a leſs thickneſs. Now the changes likely to be wrought in the denſity or magnitude of the parts of vegetables by withering ſeem not greater, than are ſufficient to change their colour into thoſe of the ſame order; but the yellow and red of the fourth order are not full enough to agree with thoſe, into which theſe ſubſtances change, nor is the green of the ſecond ſufficiently good to be the colour of vegetables; ſo that their colour muſt of neceſſity be of the third order.

15. THE blue colour of ſyrup of violets our author ſuppoſes to be of the third order; for acids, as vinegar, with this ſyrup change it red, and ſalt of tartar or other alcalies mixed therewith turn it green. But if the blue colour of the ſyrup were of the ſecond order, the red colour, which acids by attenuating its parts give it, muſt be of the firſt order, and the green given it by alcalies by incraſſating

its particles ſhould be of the ſecond; whereas neither of thoſe colours is perfect enough, eſpecially the green, to anſwer thoſe produced by theſe changes; but the red may well enough be allowed to be of the ſecond order, and the green of the third; in which caſe the blue muſt be likewiſe of the third order.

16. The azure colour of the skies our author takes to be of the firſt order, which requires the ſmalleſt particles of any colour, and therefore moſt like to be exhibited by vapours, before they have ſufficiently coaleſced to produce clouds of other colours.

17. The moſt intenſe and luminous white is of the firſt order, if leſs ſtrong it is a mixture of the colours of all the orders. Of the latter ſort he takes the colour of linnen, paper, and ſuch like ſubſtances to be; but white metals to be of the former ſort. The arguments for it are theſe. The opacity of all bodies has been ſhewn to ariſe from the number and ſtrength of the reflections made within them; but all experiments ſhew, that the ſtrongeſt reflection is made at thoſe ſurfaces, which intercede tranſparent bodies differing moſt in denſity. Among other inſtances of this, the experiments before us afford one; for when air only is included between the glaſſes, the coloured rings are not only more dilated, as has before been ſaid, than when water is between them; but are likewiſe much more luminous and bright. It follows therefore, that whatever medium pervades the pores of bodies, if ſo be there

is any, thoſe ſubſtances muſt be moſt opake, the denſity of whoſe parts differs moſt from the denſity of the medium, which fills their pores. But it has been ſufficiently proved in the former part of this tract, that there is no very denſe medium lodging in, at leaſt pervading at liberty the pores of bodies. And it is farther proved by the preſent experiments. For when air is incloſed by the denſer ſubſtance of glaſs, the rings dilate themſelves, as has been ſaid, by being viewed obliquely; this they do ſo very much, that at different obliquities the ſame thickneſs of air will exhibit all ſorts of colours. The bubble of water, though ſurrounded with the thinner ſubſtance of air, does likewiſe change its colour by being viewed obliquely; but not any thing near ſo much, as in the other caſe; for in that the ſame colour might be ſeen, when the rings were viewed moſt obliquely, at more than twelve times the thickneſs it appeared at under a direct view; whereas in this other caſe the thickneſs was never found conſiderably above half as much again. Now the colours of bodies not depending only on the light, that is incident upon them perpendicularly, but likewiſe upon that, which falls on them in all degrees of obliquity; if the medium ſurrounding their particles were denſer than thoſe particles, all ſorts of colours muſt of neceſſity be reflected from them ſo copiouſly, as would make the colours of all bodies white, or grey, or at beſt very dilute and imperfect. But on the other hand, if the medium in the pores of bodies be much rarer than their particles, the colour reflected will be ſo little changed by the obliquity of the rays, that the colour produced by the rays, which fall near the perpendicular, may ſo much abound in the reflected light, as to give the body their colour with little allay. To this may be added, that when the difference of the contiguous tranſparent ſubſtances is the ſame, a colour reflected from the denſer ſubſtance reduced into a thin plate and ſurrounded by the rarer will be more briſk, than the ſame colour will be, when reflected from a thin plate formed of the rarer ſubſtance, and, ſurrounded by the denſer; as our author experienced by blowing glaſs very thin at a lamp furnace, which exhibited in the open air more vivid colours, than the air does between two glaſſes. From theſe conſiderations it is manifeſt, that if all other circumſtances are alike, the denſeſt bodies will be moſt opake. But it was obſerved before, that theſe white metals can hardly be made ſo thin, except by being diſſolved in corroding liquors, as to be rendred tranſparent; though none of them are ſo denſe as gold, which proves their great opacity to have ſome other cauſe beſides their denſity; and none is more fit to produce this, than ſuch a ſize of their particles, as qualifies them to reflect the white of the firſt order.

18. For producing black the particles ought to be ſmaller than for exhibiting any of the colours, viz. of a ſize anſwering to the thickneſs of the bubble, where by reflecting little or no light it appears colourleſs; but yet they muſt not be too ſmall, for that will make them tranſparent through deficiency of reflections in the inward parts of the body, ſufficient to ſtop the light from going through it; but they muſt be of a ſize bordering upon that

diſpoſed to reflect the faint blue of the firſt order, which affords an evident reaſon why blacks uſually partake a little of that colour. We ſee too, why bodies diſſolved by fire or putrefaction turn black: and why in grinding glaſſes upon copper plates the duſt of the glaſs, copper, and ſand it is ground with, become very black: and in the laſt place why these black ſubſtances communicate ſo eaſily to others their hue; which is, that their particles by reaſon of the great minuteneſs of them eaſily overſpread the groſſer particles of others.

19. I SHALL now finiſh this chapter with one remark of the exceeding great poroſity in bodies neceſſarily required in all that has here been ſaid; which, when duly conſidered, muſt appear very ſurprizing; but perhaps it will be matter of greater ſurprize, when I affirm that the ſagacity of our author has diſcovered a method, by which bodies may eaſily become ſo; nay how any the leaſt portion of matter may be wrought into a body of any aſſigned dimenſions how great ſo ever, and yet the pores of that body none of them greater, than any the ſmalleſt magnitude propoſed at pleaſure; notwithſtanding which the parts of the body ſhall ſo touch, that the body itſelf ſhall be hard and ſolid[a]. The manner is this: ſuppoſe the body be compounded of particles of ſuch figures, that when laid together the pores found between them may be equal in bigneſs to the particles; how this may be effected, and yet the body be hard and ſolid, is not difficult to underſtand; and the pores of ſuch a body

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[a] Opt. pag. 243.

dy may be made of any propoſed degree of ſmallneſs. But the ſolid matter of a body ſo framed will take up only half the ſpace occupied by the body; and if each conſtituent particle be compoſed of other leſs particles according to the ſame rule, the ſolid parts of ſuch a body will be but a fourth part of its bulk; if every one of theſe leſſer particles again be compounded in the ſome manner, the ſolid parts of the whole body ſhall be but one eighth of its bulk; and thus by continuing the compoſition the ſolid parts of the body may be made to bear as ſmall a proportion to the whole magnitude of the body, as ſhall be deſired, notwithſtanding the body will be by the contiguity of its parts capable of being in any degree hard. Which ſhews that this whole globe of earth, nay all the known bodies in the univerſe together, as far as we know, may be compounded of no greater a portion of ſolid matter, than might be reduced into a globe of one inch only in diameter, or even leſs. We ſee therefore how by this means bodies may eaſily be made rare enough to tranſmit light, with all that freedom pellucid bodies are found to do. Though what is the real ſtructure of bodies we yet know not.

CHAP. III.

Of the REFRACTION, REFLECTION, and INFLECTION of LIGHT.

THUS much of the colours of natural bodies; our method now leads us to ſpeculations yet greater, no leſs than to lay open the cauſes of all that has hitherto been related. For it muſt in this chapter be explained, how the priſm ſeparates the colours of the ſun's light, as we found in the firſt chapter; and why the thin tranſparent plates diſcourſed of in the laſt chapter, and conſequently the particles of coloured bodies, reflect that diverſity of colours only by being of different thickneſſes.

2. FOR the firſt it is proved by our author, that the colours of the ſun's light are manifeſted by the priſm, from the rays undergoing different degrees of refraction; that the violet-making rays, which go to the upper part of the coloured image in the firſt experiment of the firſt chapter, are the moſt refracted; that the indigo-making rays are refracted, or turned out of their courſe by paſſing through the priſm, ſomething leſs than the violet-making rays, but more than the blue-making rays; and the blue-making rays more than the green; the green-making rays more than the yellow; the yellow more than the orange; and the orange-making rays more than the red-making, which are leaſt of all refracted. The firſt proof of this, that rays of different colours are refracted unequally is this. If you take any body, and paint one half of it red and the other half blue, then upon viewing it through a priſm thoſe two parts ſhall appear ſeparated from each other; which can be cauſed no otherwiſe than by the priſm's refracting the light of one half more than the light of the other half. But the blue half will be moſt refracted; for if the body be ſeen through the priſm in ſuch a ſituation, that the body ſhall appear

lifted upwards by the refraction, as a body within a baſon of water, in the experiment mentioned in the firſt chapter, appeared to be lifted up by the refraction of the water, ſo as to be ſeen at a greater diſtance than when the baſon is empty, then ſhall the blue part appear higher than the red; but if the refraction of the priſm be the contrary way, the blue part ſhall be depreſſed more than the other. Again, after laying fine threads of black ſilk acroſs each of the colours, and the body well inlightened, if the rays coming from it be received upon a convex glaſs, ſo that it may by refracting the rays caſt the image of the body upon a piece of white paper held beyond the glaſs; then it will be ſeen that the black threads upon the red part of the image, and thoſe upon the blue part, do not at the ſame time appear diſtinctly in the image of the body projected by the glaſs; but if the paper be held ſo, that the threads on the blue part may diſtinctly appear, the threads cannot be ſeen diſtinct upon the red part; but the paper muſt be drawn farther off from the convex glaſs to make the threads on this part viſible; and when the diſtance is great enough for the threads to be ſeen in this red part, they become indiſtinct in the other. Whence it appears that the rays proceeding from each point of the blue part of the body are ſooner united again by the convex glaſs than the rays which come from each point of the red parts[a]. But both theſe experiments prove that the blue-making rays, as well in the ſmall refraction of the convex glaſs, as in the greater refraction of the priſm, are more bent, than the red-making rays.

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[a] Newt. Opt. B. I. part. 1. prop. I.

3. THIS ſeems already to explain the reaſon of the coloured ſpectrum made by refracting the ſun's light with a priſm; though our author proceeds to examine that in particular, and proves that the different coloured rays in that ſpectrum are in different degrees refracted; by ſhewing how to place the priſm in ſuch a poſture, that if all the rays were refracted in the ſame manner, the ſpectrum ſhould of neceſſity be round: whereas in that caſe if the angle made by the two ſurfaces of the priſm, through which the light paſſes, that is the angle DFE in fig. 126, be about 63 or 64 degrees, the image inſtead of being round ſhall be near five times as long as broad; a difference enough to ſhew a great inequality in the refractions of the rays, which go to the oppoſite extremities of the image. To leave no ſcruple unremoved, our author is very particular in ſhewing by a great number of experiments, that this inequality of refraction is not caſual, and that it does not depend upon any irregularities of the glaſs; no nor that the rays are in their paſſage through the priſm each ſplit and divided; but on the contrary that every ray of the ſun has its own peculiar degree of refraction proper to it, according to which it is more or leſs refracted in paſſing through pellucid ſubſtances always in the ſame manner[a]. That the rays are not ſplit and multiplied by the refraction of the priſm, the third of the experiments related in our firſt chapter ſhews very clearly; for if they were, and the length of the ſpectrum in the firſt refraction were thereby occaſioned, the breadth ſhould be no leſs dilated by the croſs refraction of the ſe-

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[a] Opt. B. I. part. 1. prop. 2.

cond priſm; whereas the breadth is not at all increaſed, but the image is only thrown into an oblique poſture by the upper part of the rays which were at firſt more refracted than the under part, being again turned fartheſt out of their courſe. But the experiment moſt expreſsly adapted to prove this regular diverſity of refraction is this, which follows[*]. Two boards AB, CD (in fig. 130.) being erected in a darkened room at a proper diſtance, one of them AB being near the window-ſhutter EF, a ſpace only being left for the priſm GHI to be placed between them; ſo that the rays entring at the hole M of the window-ſhutter may after paſſing through the priſm be trajected through a ſmaller hole K made in the board AB, and paſſing on from thence go out at another hole L made in the board CD of the ſame ſize as the hole K, and ſmall enough to tranſmit the rays of one colour only at a time; let another priſm NOP be placed after the board CD to receive the rays paſſing through the holes K and L, and after refraction by that priſm let thoſe rays fall upon the white ſurface QR. Suppoſe firſt the violet light to paſs through the holes, and to be refracted by the priſm NOP to *s*, which if the priſm NOP were removed ſhould have paſſed right on to W. If the priſm GHI be turned ſlowly about, while the boards and priſm NOP remain fixed, in a little time another colour will fall upon the hole L, which, if the priſm NOP were taken away, would proceed like the former rays to the ſame point W; but the refraction of the priſm NOP ſhall not carry theſe rays to *s*, but to ſome place leſs diſtant from W as

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[*] Opt. B. I. part 1. Expec. 6.